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A New Approach for Error Reduction in Localization for Wireless Sensor Networks

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***Abstract*— Localization is one of the most challenging and important issues in wireless sensor networks (WSNs), especially if cost effective approaches are demanded. Distance measurement based on RSSI (Received Signal Strength Indication) is a low cost and low complexity of the distance measurement technique, and it is widely applied in the range-based localization of the WSN. The RSS (Received Signal Strength) used to estimate the distance between an unknown node and a number of reference nodes with known co-ordinates. Location of the target node is then determined by trilateration. Log-normal shadowing model, can better describe the relationship between the RSSI value and distance. Non-line of sight and multipath transmission effects as the indoor environment, the distance error or ranging error is large. In this paper, experimental results that are carried out to analyze the sensitivity of RSSI measurements in an indoor environment for various power levels are presented. Location error influenced by distance measure error and network connectivity is analyzed.**

***Index Terms*— Localization, Received signal strength indicator (RSSI), Power levels, Anchor.**

I. Introduction

Localization is the process by which sensor nodes determine their location. It is important when there is an uncertainty of the exact location of some fixed or mobile devices. An effective localization algorithm uses all the available information from the wireless sensor nodes to infer the position of the individual nodes. Sensor locations allows one to use diverse sensor data more efficiency, plan resource routing priorities to support network services or perform surveillance effectively [3]. Many applications, such as object tracking, location based routing, coverage management and collaborative signal processing, require that sensor nodes be able to automatically and accurately determine their absolute or relative (with respect to other nodes) locations. Consider the example, where a sensor network is used to detect a fire event in a forest. Once a sensor node has detected that the temperature is higher than a certain threshold, it sends a message to the central authority by relaying through other nodes in a multi-hop manner. The message needs to indicate the location of the node which detected the event. Thus, localization of sensor nodes is important in some applications.

Anchor (or) beacon nodes and unknown nodes are the two types of nodes employed in localization. A beacon is a node aware of its location (e.g. equipped with GPS). The nodes of initially unknown positions will be called unknown nodes. After the sensor node has been deployed, the mobile beacon assists the unknown nodes in localizing themselves. The mobile beacon can be a human operator, an unmanned vehicle deployed with the sensor network, or in the case of a deployment from a plane, the plane itself. With regard to the mechanisms used for estimating location, the localization protocols are divided into two categories: range-free and range-based. In the range free approaches, the algorithms do not need range hardware support and are immune to range measurement errors while providing less accurate but still acceptable localization results. In the range-based approaches, the algorithms require more sophisticated range hardware support to acquire absolute point-to-point distance estimates or angle estimates for calculating locations. The range-based approaches provide more accurate localization results than the range-free algorithms. The Time of Arrival (TOA) and time difference of arrival (TDOA), the angle of arrival (AOA) method, and received signal strength indicator (RSSI) method are popular range based method [13] [16].

Section 2 describes the related work. Section 3 describes the distance estimation based on RSSI. Section 4 explains the path loss model used for location estimation from the experimental measurements. A new approach is explained in Section 5 followed by simulation results and Section 6 follows the conclusion.

II. Related Work

Location is considered an important attribute in WSN. With regard to the mechanisms used for estimating location, the localization algorithms can be divided into two categories:

Range-based and range-free. The range-based algorithms need to measure precise distance or orientation between neighbour nodes, and then use the information to localize nodes. Range-free algorithms use estimated distance instead of metrical distance to localize nodes. The time of arrival (TOA), and time difference of arrival (TDOA), the angle of arrival (AOA) method, and received signal strength indicator (RSSI) method are all popular range based methods [2], [6]. Since the emergence of GPS systems, the various techniques available to identify locations, TOA has been of the least interest. Two different signals which have different propagation speeds are used for TDOA positioning. The signal can be a pilot from a mobile node, when the mobile's absolute time is unknown, or it can be unknown as is the case in electronic warfare. AOA is defined as the angle

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between the propagation direction of an incident wave and some reference direction which is also called orientation [10]. One common approach to obtain AOA measurements is to use an antenna array on each sensor node. RSSI is the most fundamental method [7]. Both theoretical and empirical models are used to translate signal strength into estimated distance. Due to its easy implementation and there is no need for additional hardware, RSSI has been widely used. It is also used in this paper. In the RSSI method, the sender's transmitting intensity can be known, and the receiver can compute the signal loss after receiving message in existing localization methods. RSSI based localization is a range based technique that utilizes the built in RSSI circuitry inside the sensor's transceivers chipsets [12].The characteristics of RSSI-curves for different indoor environments for two different frequencies are analyzed .Then, the location dependent errors are reduced and introduced a boundary under which the sampled data was qualified for localization [8]. For noisy indoor environments an average positioning error of 50 cm on an area of 3.5 x 4.5 m is possible by choosing the RF and algorithm parameters based on empirical studies. [11]

The range-free algorithms are the centroid, approximate point in Triangle Test (APIT), DV-Hop (Distance Vector- HOP) and Amorphous, and so on [1],[6],[15]. In centroid scheme, the anchor nodes send out beacon signals which include their information of localization to neighbour nodes at periodic intervals. The location of the node is then estimated to be the centroid of the anchor nodes from which it can receive beacon packets. The centroid method is the simplest possible anchor based localization but it needs too many anchor nodes. To avoid accumulation of location errors in propagating location information, the APIT test [5] manages to infer the location of a non-anchor node from the region it could possibly reside in. Each non-anchor node runs the Point in Triangle (PIT) tests to find the triangle regions it resides in. However, it is hard for the non-anchor nodes to perform the exact PIT test. DV-Hop assumes a heterogeneous network which is consisted of sensor nodes and anchor nodes [6]. Instead of single hop broadcasts, anchor nodes flood their location throughout the network maintaining a running hop count at each node along the way. Nodes estimate their own location based on the received information of anchor nodes locations, the hop-count from the corresponding anchor, and the average-distance per hop, a value obtained through anchor communication. Although the range-free algorithms cannot obtain as high accuracy of localization as range-based algorithms, they provide an economic cost. There are some typical RSSI localization algorithms, such as RADAR. A radio-frequency (RF) based system, named RADAR, for locating, recording and processing signal strength information at multiple base stations positioned to provide overlapping coverage in the area of interest [16].

III. RSSI Based Distance Estimation

Localization algorithms require a distance to estimate the position of unknown devices. One possibility to acquire a distance is measuring the received signal strength of the incoming radio signal. RSSI is a unit less metric used to measure the power of the received radio signal [14][15]. It is represented by one-byte integer and can assume any value in the range 0 to 255. TelosB motes are used for measuring RSSI values. Each TelosB mote has an inbuilt IEEE 802.15.4 radio (CC2420) with an integrated 2.4 GHz – 2.4835 GHz antenna. CC2420 chip has an inbuilt RSSI register and its value is RSSI.RSSI_VAL.

CC2420 has a built-in RSSI (Received Signal Strength Indicator) providing a digital value that can be read from the 8 bit, signed 2's complement RSSI.RSSI_VAL registers. The RSSI value is always averaged over 8 symbol periods (128 µs). The RSSI_VALID status bit (indicates when the RSSI value is valid, meaning that the receiver has been enabled for at least 8 symbol periods. The RSSI register value RSSI.RSSI_VAL can be referred to the power P at the RF pins by using the following equations:

P = RSSI_VAL + RSSI_OFFSET [dBm]

Where the RSSI_OFFSET is found empirically during system development from the front end gain. RSSI_OFFSET is approximately –45. E.g. if reading a value of –20 from the RSSI register, the RF input power is approximately –65 dBm.

The RSSI register value RSSI.RSSI_VAL is calculated and continuously updated for each symbol after RSSI has become valid.

The RSSI can be used to find the power P of the RF signal in dBm, using the following equation

$$RSS = RSSI\_VAL + RSSI\_OFFSET\ [dBm] \tag{1}$$

Where RSSI_OFFSET, is a calibration offset value, found empirically during CC2420 system development from the front end gain. This value was found to be approximately equals -45.

Hence the Received Signal Strength (RSS) can be expressed as

$$RSS = RSSI\_VAL - 45 [dBm] \tag{2}$$

A. Log-distance path loss model

$$P_L(d) = P_t(dBm) - P_r(d)\ (dBm) \tag{3}$$

Where P_L is the Total path loss in dB, P_t is the Transmitted power in dBm, P_r – Received power in dBm .

Propagation model used in indoor wireless sensor network [4] is given by

$$P_L(d) = P_L(d_0) + 10n \log(d/ d_0) + X_\sigma \tag{4}$$

Where $P_L(d_0)$ – Path loss at the reference distance d_0 in dB, d_0 – Reference distance ($\approx$ 1m), d – distance from sender, n – Path loss exponent, X_σ – Zero-mean Gaussian random variable.

Path loss exponent measures the rate at which the RSS decreases with distance, and its value depends on the specific propagation environment [9]

$$P_r(d) = A - 10n \log(d) \tag{5}$$

Where $A = P_t - P_L(d_0)$

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IV. Analyzing And Optimizing RSSI Measurements

The entire experiment has been carried out in an indoor environment. The RSS measurements are prone to noise and interference, which leads to error in localization. All the deployed nodes are kept at same altitude from surface of floor, with their antennas pointing upwards and directly facing each other. For various power levels (0, 1, 2, 3, 6, 9, 15, 21, 27, 31) which is equal to (-25…..0) dBm experiments are carried out in an indoor environment [3].

In TelosB mote the highest power level is zero. The path loss models for the various power levels are characterized. At each distance d, 40 RSSI values are collected then averaged to get the average RSSI. Average power in dBm is calculated using equation (2). Path loss exponent (n) and A values for each power level is calculated by solving equation (5) for various RSSI values and the corresponding mean is taken. Average power of RF signal, n and A values are used in the below equation (6) to calculate the distance.

$$d=10^{-(Pr\ (d)+A)/10n} \qquad (6)$$

The TelosB mote used to measure RSSI values for various power levels in an indoor environment. TelosB platform delivers low power consumption allowing for long battery life as well as fast wakeup from sleep state [8].

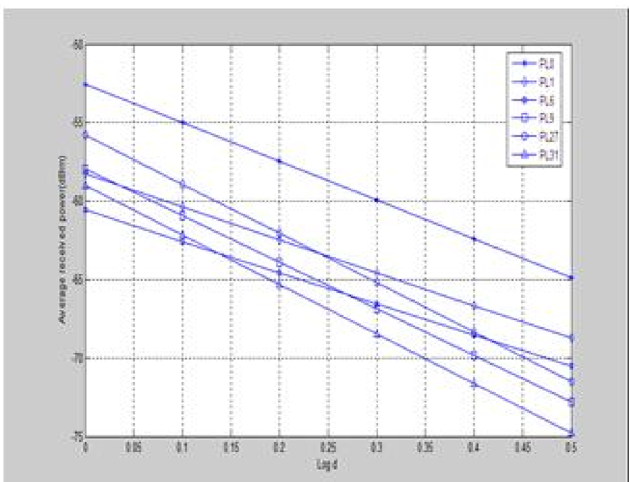

Fig.1: Linear Curve fitting

Table I: Linear regression equation for various power levels

Power Level	Mean Error using RSSI(m)	Mean Error using Improved RSSI(m)
0	0.16	0.06
1	0.13	0.088
2	0.2	0.063
3	0.087	0.012
6	0.163	0.026
9	0.15	0.025
15	0.52	0.14
21	0.54	0.34
27	0.94	0.5
31	0.49	0.15

Figure 1, shows the linear curve fitting. It is used to get the function between RSSI measurement and distance, shown in Table 1. These linear equations are used to estimate the distance according to the RSSI measurements for various power levels. Error is calculated between the estimated distance and the true distance.

V. Improved Rssi Method

Using Log-distance path loss model to calculate the distance between beacon node and unknown node, this is determined by parameter A and n. In order to reduce the measurement error further, Log-distance path loss model is modified based on the mean error for each power levels. For all the power levels, same seven telosB motes are used for different distances.

Each power level, the mean distance error is calculated and it is implemented using the following equation

$$d = P + E \qquad (7)$$

used to reduce the distance error.

Where 'P' is the estimated distance, 'E' is the distance error, 'd' is the actual distance

$$P_r(d) = A- 10n \log (P+E) \qquad (8)$$

Table 2 shows error reduction using improved RSSI method. For power level 2, 0.2m is the mean distance error using path loss model and linear curve fitting from the experimental measures. 0.06m is the mean distance error after using new approach. 32% of the error is reduced. For power level 27, 0.94 is the mean distance error using path loss model and linear curve fitting from the experimental measures. 0.5m is the mean distance error after using new approach. 53% of the error is reduced. This result shows for increasing power levels, the error reduction percentage also increased.

Table II: Error reduction using improved RSSI method for various power levels

Power Level	Linear Regression Equation	Path Loss Exponent(n)
0	Y=-24.7x - 52.54	2.47
1	Y=-21.01x - 58.49	2.1
2	Y=-20.46x – 59.49	2.05
3	Y=-22.7x – 58.75	2.27
6	Y=-19.9x – 60.58	1.99
9	Y=.29.616x - 57.99	2.96
15	Y=-22.48x – 58.18	2.24
21	Y=-31.05x - 57.73	3.10
27	Y=-31.38x - 55.79	3.14
31	Y=-31.59x - 59	3.15

A. Variation of the transmission power

The transmission power and the frequency determine the maximum range of radio waves. While the maximum transmission power might be appropriate for long distance communication (disregarding energy requirements), differences in the RSSI are hardly visible for small distances

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between transmitters and receivers. However, the measurement of short distances for the localization in closed areas with small dimensions is important. Thus, the transmission power must be well controlled for meaningful RSSI based distance measurements [10].

B. Position computation

It is done by using Maximum Likelihood Estimation (MLE). For this estimation minimum three anchor nodes are needed.

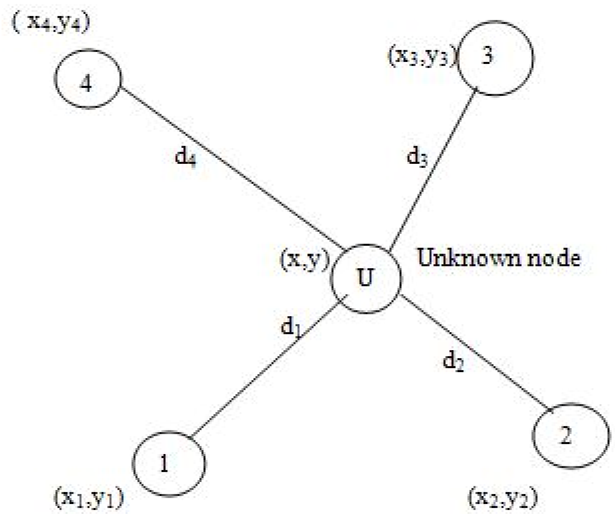

Fig: 2 Localization using RSSI measurements

Figure 2 shows the scenario of the nodes localization used for this experiment. Node U is the unknown node. Node1, 2, 3 and 4 are the anchor nodes. Distance is calculated using the equations for position computation are shown as following

$$\left.\begin{aligned} d_1^2 &= (x - x_1)^2 + (y - y_1)^2 \\ d_2^2 &= (x - x_2)^2 + (y - y_2)^2 \\ &\;\;\vdots \\ d_n^2 &= (x - x_n)^2 + (y - y_n)^2 \end{aligned}\right\} \quad (9)$$

Here distance 'd' is replaced by the following equation

$$d_i = P_i + E_i$$

Where P_i = Estimated distance, E_i = Distance Error. To minimize this error $E_i = 0$

For the above scenario shown in figure 2, anchor node coordinates and distances to unknown node are (1,1.5,1.75)m, (3,1,1.1)m, (4.5,2,2)m and (5,1,2.7)m. x and y values for the experimental RSSI measurements are (2.1,2.4).After applied d_i in (9) and for the above values, the position is computed . The and y values are (2.4,2.3). 92% position error is reduced using the improved RSSI method.

C.Simulation Results

Figure 3, shows the simulation results of error reduction method using the RSSI values which is taken in the real time scenario. TelosB motes are used to take RSSI values. Motes are placed in an indoor environment. Path loss exponent (n) and model parameter (A) were obtained using measured RSSI values for various power levels are mentioned in the above figures. Figure 3.1, shows the distance error (-0.3, -0.6, -0.5, -0.2, 0.4, -0.9) using the measured RSSI values and the distance error (-0.1, -0.4, -0.3, 0, -0.2, -0.7) using improved RSSI for power level zero (maximum power in dBm). Comparing these two methods, 38% error reduction is obtained using improved RSSI method for power level zero. Figure 3.10, shows the distance error (-0.55, -0.6, -0.7, -0.3, -0.3, 1.6) using the measured RSSI values and the distance error (-0.1, -0.1, -0.2, 0.2, 0.2, 1.1) using improved RSSI for power level 31 (lowest power-0dBm). Comparing these two methods, 31% error reduction is obtained using improved RSSI method for power level 31.

Similarly error reduction percentages for all other power levels are calculated. Figure 3 shows, comparisons of error reduction using RSSI method and Improved RSSI method and it shows more error reduction using improved RSSI method. Average error reduction using improved RSSI method is 36%.

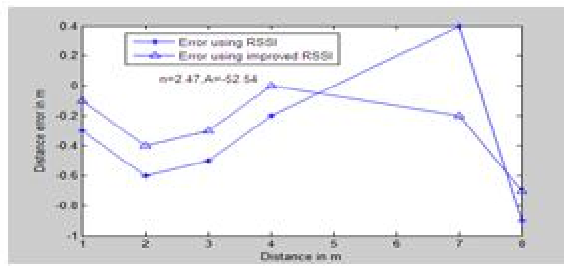

Fig.3.1: Power level 0

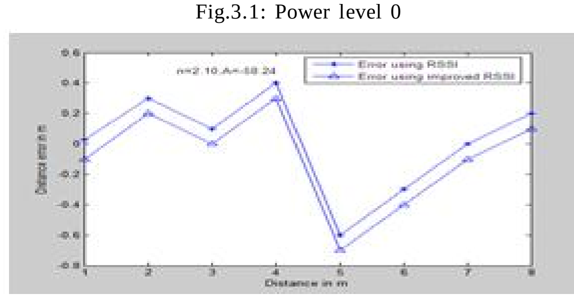

Fig.3.2: Power level 1

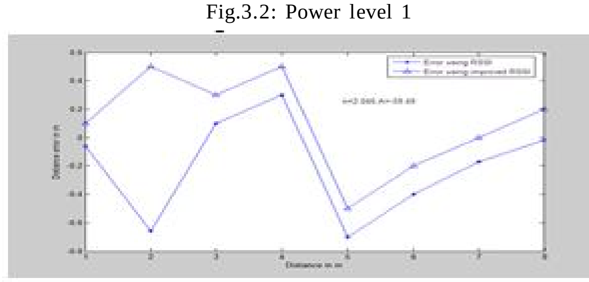

Fig.3.3: Power level 2

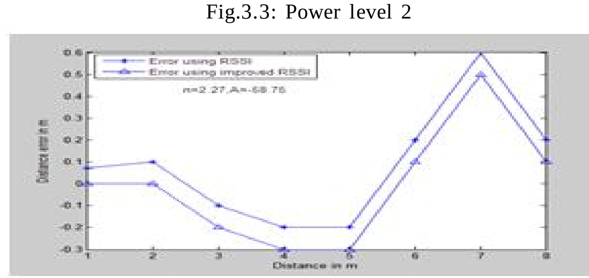

Fig.3.4: Power level 3

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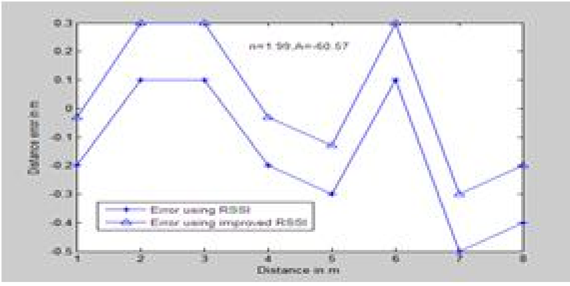

Fig.3.5: Power level 6

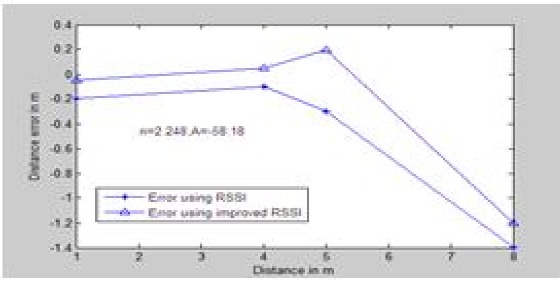

Fig.3.6: Power level 9

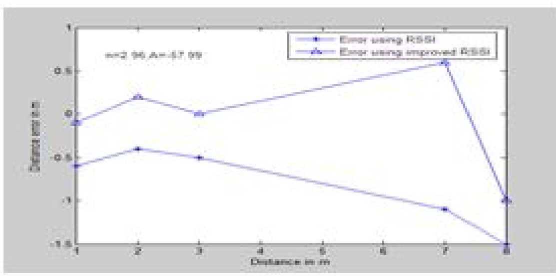

Fig.3.7: Power level 15

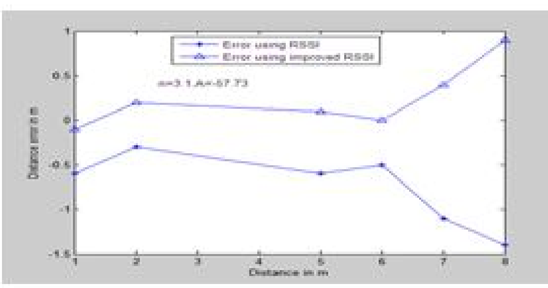

Fig.3.8: Power level 21

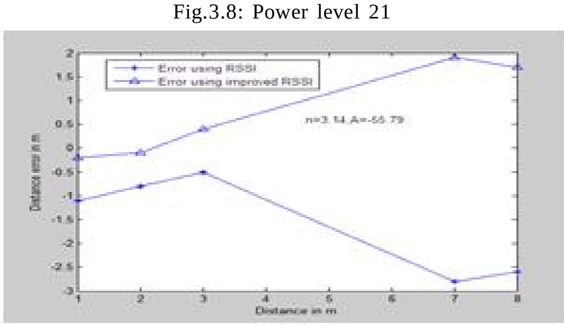

Fig.3.9: Power level 27

VI. Conclusion

In this work, RSSI values for various power levels are measured using TelosB motes to derive the log normal path loss model for indoor environment. Linear regression analysis is used to derive these log normal path loss model based

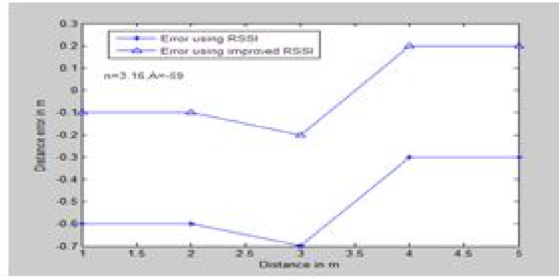

Fig.3.10: Power level 31

Fig 3: The analysis of errors in the distance measurement based on RSSI and improved RSSI

on the measured RSSI values. Distance between unknown node and anchor node was derived using this model. Simulation results shows that the better distance estimation can be done using improved RSSI method. 36 % average error reduction for various power levels obtained by using improved RSSI. Maximum likelihood estimation used to find the position of the node.

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